Creating Value From the Waste Stream; Sustainable Aquaculture & Bioproducts

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Where?

- Oregon State University, 1975
  - Research assistant
- University of Missouri, 1975–1978
  - PhD Student
- University of California–Davis, 1978–1982
  - Assistant Professor
- Pennsylvania State University, 1982–1987
  - Associate Professor
- Clemson University, 1987–2009
  - Professor and Endowed Chair
- University of Missouri, 2009–Present
  - Professor

University of California-Berkley, W.J. Oswald, 1979

Paddle-wheel Mixed High-rate Ponds for Wastewater Treatment

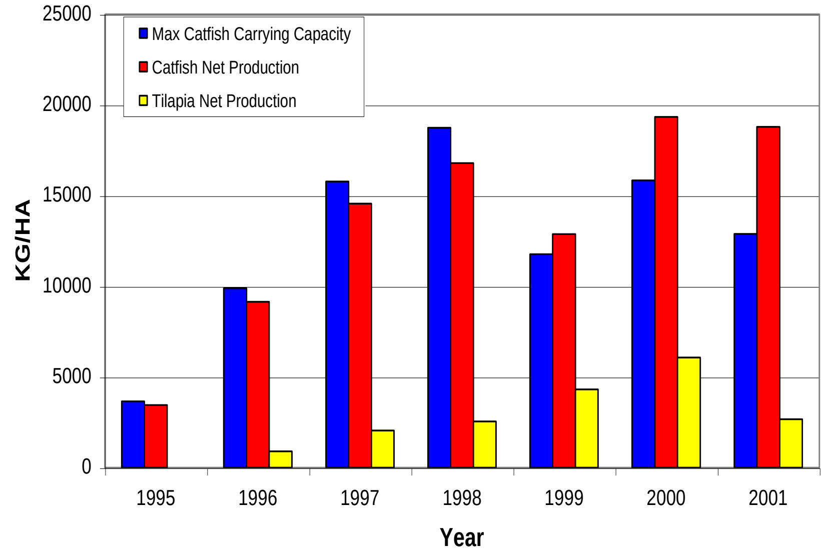
Lessons

- 4-5X algal productivity in high-rate ponds
- algal harvesting costly; discharge land applied
- culture stability issues

Clemson University, 1989-2009
Partitioned Aquaculture Systems (PAS)

<u>Lessons</u>

- zero-discharge “green-water” aquaculture
- 15-20,000 lb/ac fish production
- tilapia co-culture for algal density/genera control maximizing system performance
- algal production, harvest and utilization



Open-Pond Algal Genera Control Using Tilapia/Shellfish Filtration

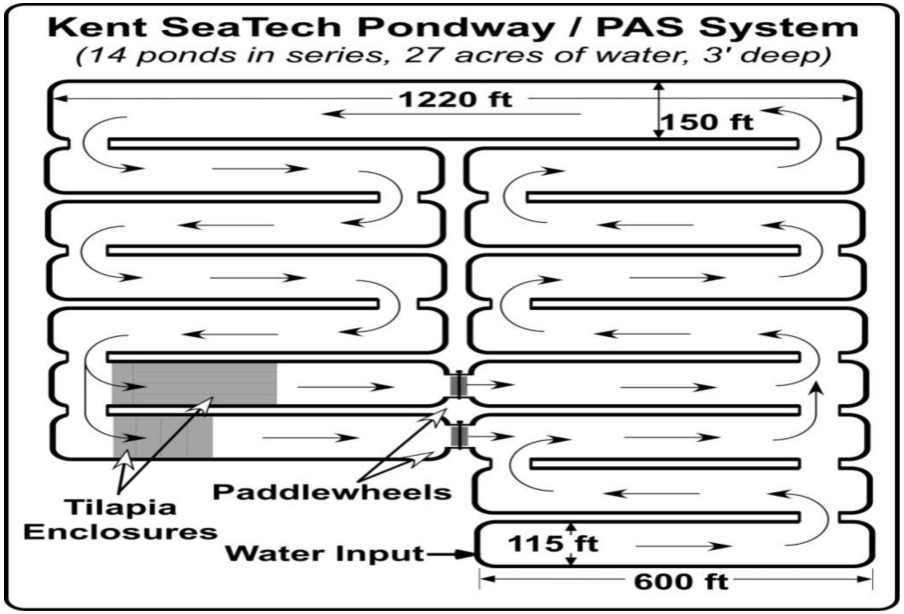

Nile tilapia

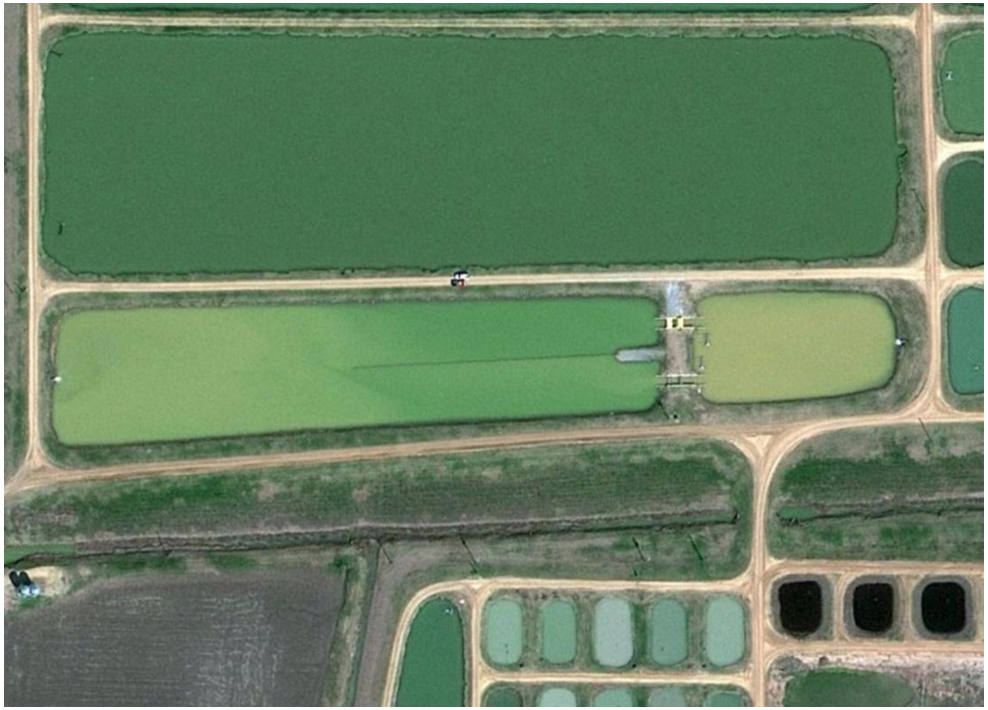
PAS Adaptations

- California Pondway System
- Alabama In-Pond Raceway
- Mississippi Spilt-Pond System

6% of Southern Catfish, 2012

Brune, D. E., C. Tucker, M. Massingill and J. Chappell, *Partitioned Aquaculture Systems*, in Aquaculture Production Systems, edited by James Tidwell, In press 2012.





Clemson University, 2000 -2009

PAS Marine Shrimp Culture

Lessons

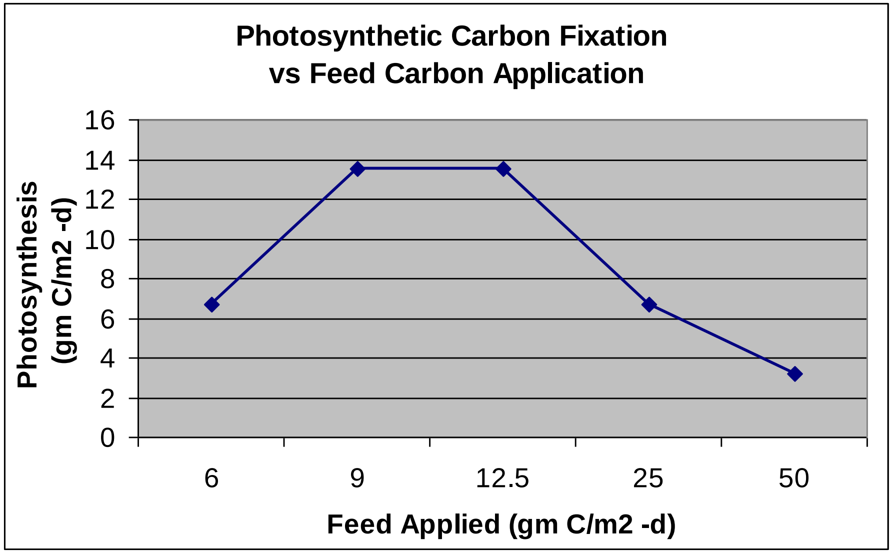
- 35,000 lbs/acre routine in "designed ecosystems"
- algal; weather sensitive
- bacterial; energy sensitive, 60+ vs. 20 hp/acre

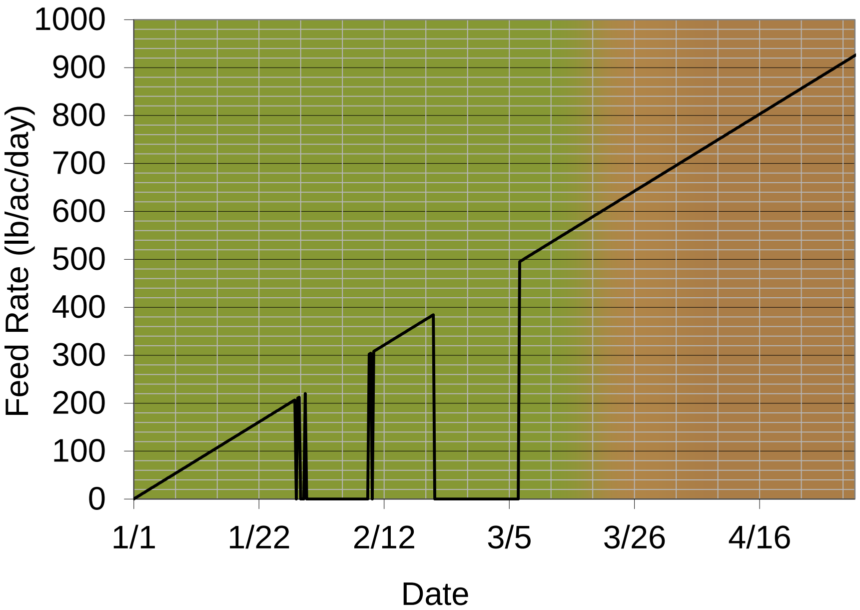
Clemson University, 1989 - 2011

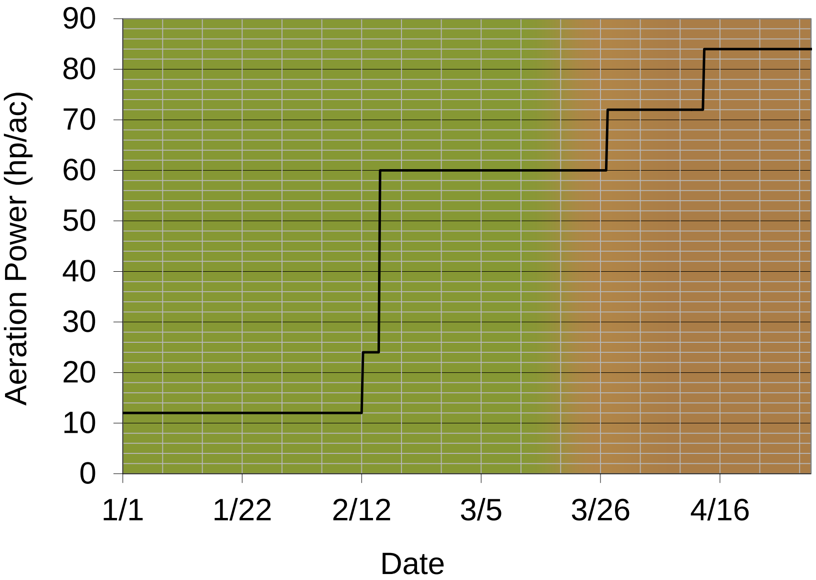
Modeling Algal/Bacterial Interactions

Lessons

- photosynthesis max, 20 g-vs/m^2-d
- aeration requirement dependent on algal/bacterial interaction
- 20,000 lb/acre shrimp in algal
- 35,000 lb/acre shrimp in bacterial

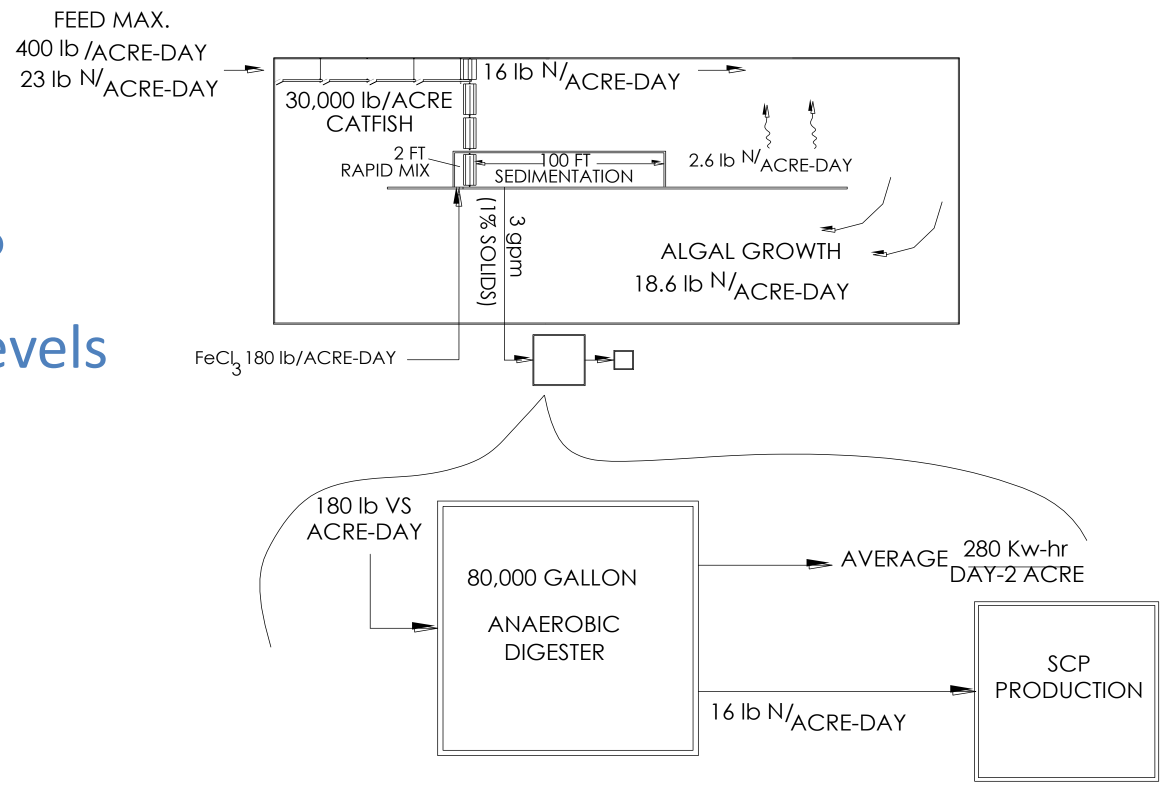


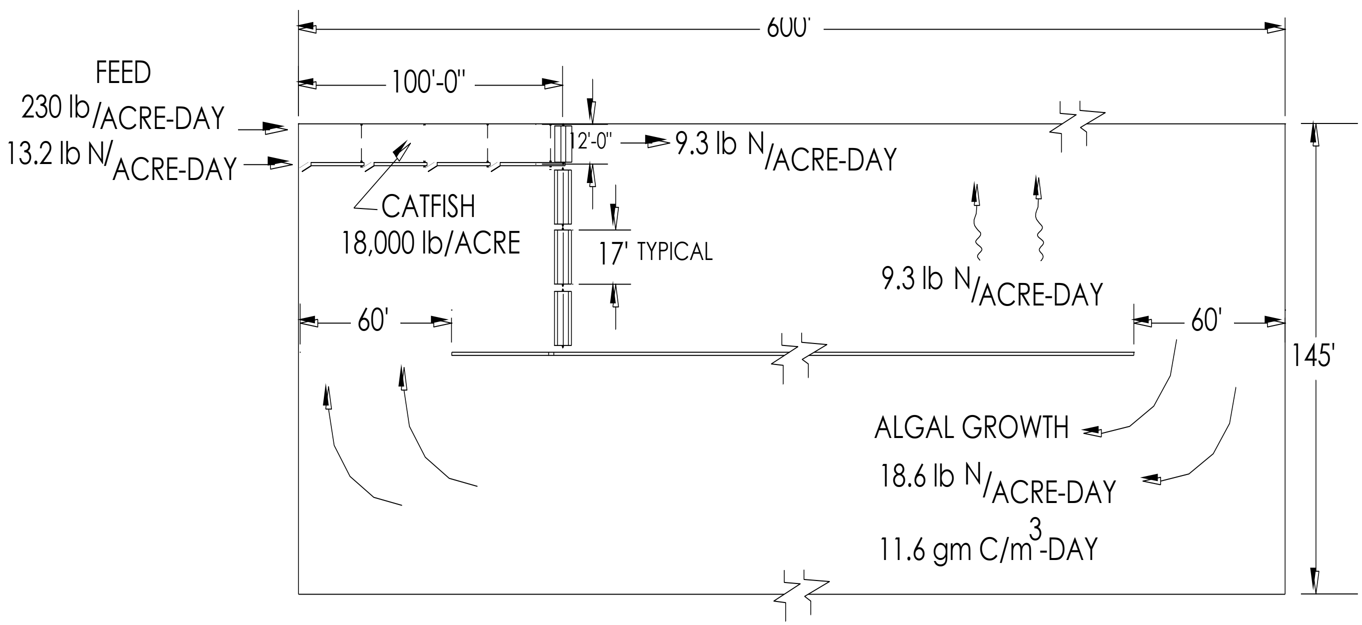




Why Algae Harvest?

- Reduced ammonia levels
- Increased feed rates
- Increased fish yields





PAS Algal Harvest and Concentration

Lessons

- tilapia-driven algal sedimentation
- slow moving belt concentrator
- 20,000 lb/acre algal biomass production

The Controlled Eutrophication Process for Nutrient Remediation of the Salton Sea at Kent Bioenergy

Lessons

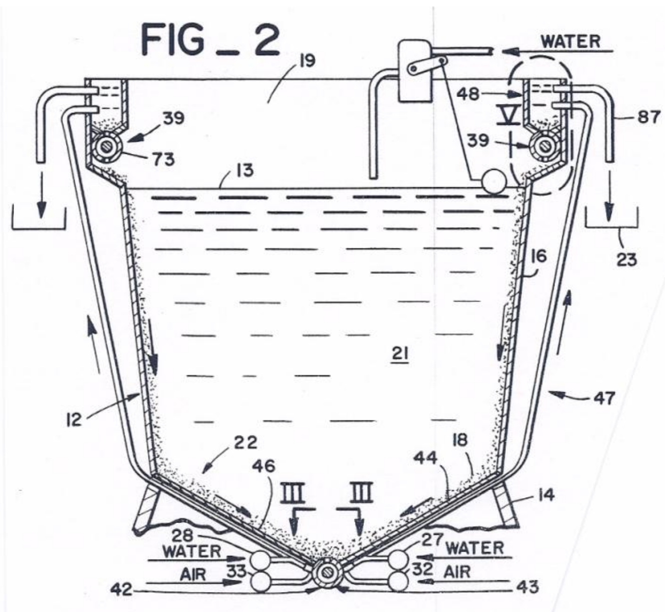
- cost-effective tilapia-driven algal harvest
- multiple products needed to off-set systems cost
- higher-value algal product needed

Brune, D. E., Eversole, A.G., J. A. Collier, and T. E. Schwedler, Controlled Eutrophication Process, U.S. Patent 7,258,790, 2007.

Brine Shrimp Algal Harvest and Conversion: 1981

<u>Lessons</u>

- aquatic-animal algal-harvest cost effective and energy efficient
- 50% conversion efficiency
- higher-value product



Brune, D. E., Flowing Bed Method and Apparatus for Culturing Aquatic Organisms, U.S. Patent 4,369,691, Jan 1983

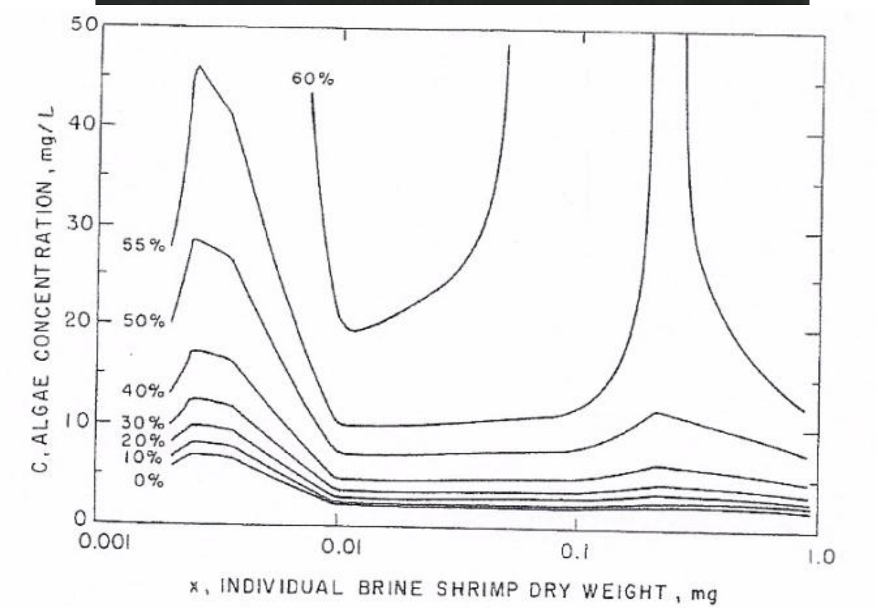


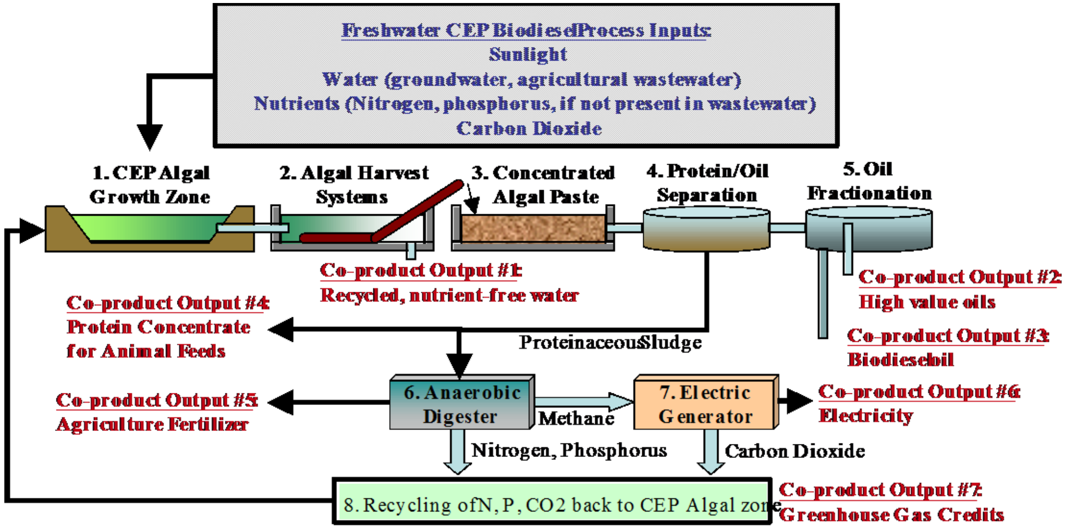
Figure 3. Lines of constant percent conversion at varying algal concentration and animal weight.

Clemson University, 2007

Aquacultural Processes for Biodiesel Production

Lessons

- high-lipid algae not needed
- low-cost extraction of animal lipids possible
- integrated systems needed



Gravity separation; oil, water and biomass fractions

Annual Shrimp Production and Importation

Estimated Farmed Shrimp Production(1000 tonnes)			
Asia	**2010**	**2011**	**2012**
China	899,600	962,000	1,048,000
Thailand	548,800	553,200	591,500
Vietnam	357,700	403,600	444,500
Indonesia	333,860	390,631	442,757
India	94,190	107,737	116,103
Bangldesh	110,000	115,000	120,000
Asia Total	**2,344,150**	**2,532,168**	**2,762,860**
Americas	**2010**	**2011**	**2012**
Ecuador	145,000	148,000	152,000
Mexico	91,500	120,000	132,000
Brazil	72,000	82,000	90,000
Colombia	16,500	15,000	14,000
Honduras	30,800	22,000	22,000
Venezuela	20,000	15,000	15,000
Amer. Total	**376,300**	**402,000**	**425,500**
Grand Total	**2,720,450**	**2,934,168**	**3,188,360**
2,934.168 tonnes = 6.5 billion lbs (tails) = 10 billion lbs heads-on			

- **Global = 10 billion lbs ($2.65/lb)**
- **U.S. Imports = 1.2 billion lbs**
- **U.S. Wild Caught = 0.20 billion lbs (16%)**
- **U.S. Production = 0.011 billion lbs (<1%)**
- **Typical U.S Production Cost ~ $3 / lb**

U.S. Production Requiring Higher-Value

Worldwide Industrialization of Shrimp Farming

- 43 billon tons of wastewater from shrimp farms enter China's coastal waters compared to 4 billion tons of industrial wastewater, increasing eutrophication*
- Shrimp consume 28% of the fish meal used in aquaculture. Demand for fish meal is depleting world's marine forage fish ; !0 million tonnes captured in diets for 30 million tonnes product
- Proposed solutions; improve feed substitutes, intensify production, move shrimp farms from coastal zones into concrete raceways under greenhouses
- Green-water shrimp production with brine shrimp algal harvest could enable zero-discharge shrimp production and eliminate need for marine protein importation

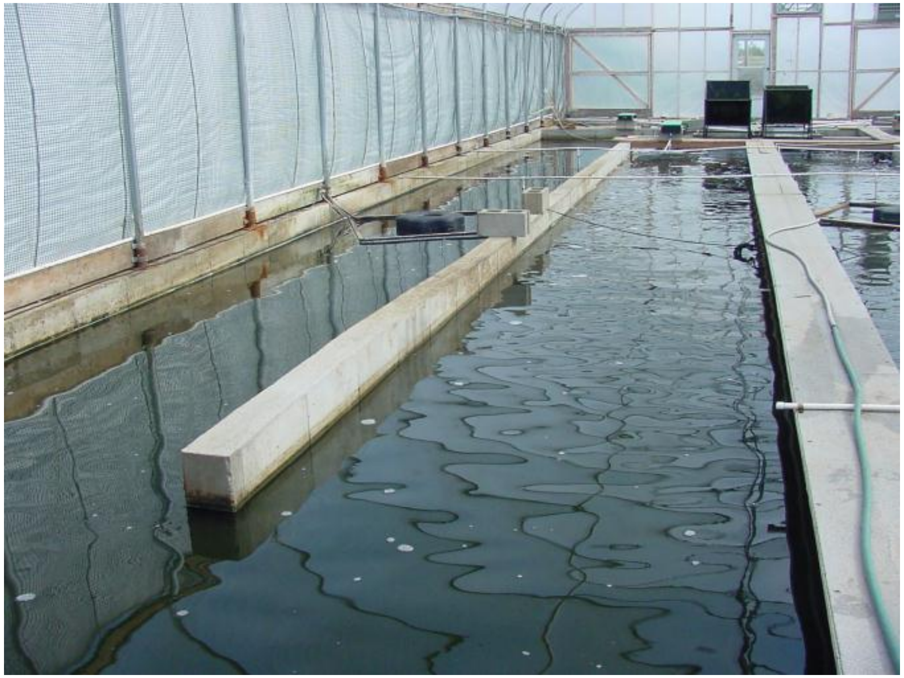
* Stokstad, E., *Down on the Shrimp Farm*, Science, 18:328, pp 1504-1505,June, 2010.

University of Missouri 2012

Sustainable Seafood and Bioproducts Co-production

Zero-discharge "green-water" aquaculture production with bioprocessing of algal biomass for protein and bioenergy co-production

Photosynthetic Biomass Production



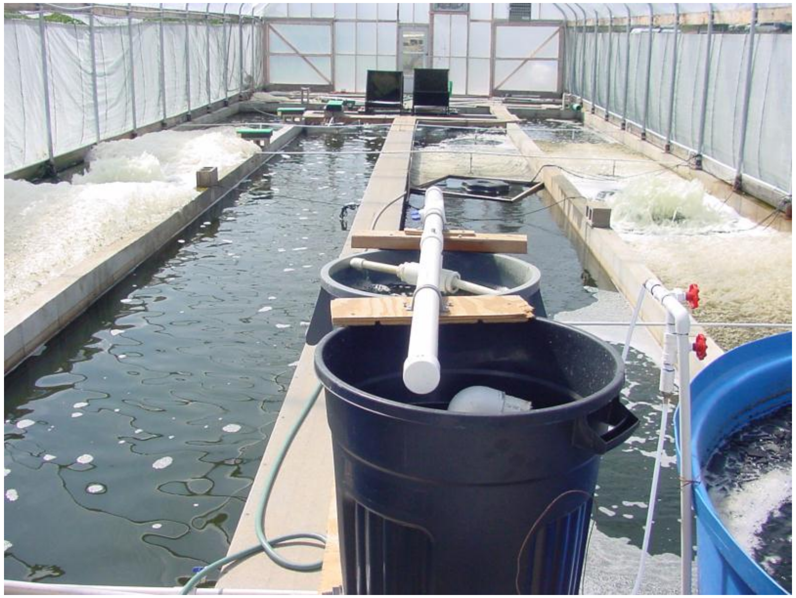
- Two-100 m^2 (0.01 ha) paddlewheel driven raceways; 60 cm deep
- Light/dark bottles of 22-50 mg O_2/l-d; 10-20 gm VS/m^2-d
- 160 gms N-unit/d; 250-lb feed/ac-d; 25,000 lb/ac aquaculture production
- 9 ton/ac-200 d photosynthetic algal biomass production
- Cyanobacteria dominance with *Artemia* filtration only

Marine shrimp production; Pacific White, *Litpenaeus vanname*

Feed Rate lb/acre-day	Production[1] lb/acre	Nitrogen Loading[2] gm-N/m²	mg-N/l	Photosynthesis[3] gm-C/m²d	mg O2/l
100	3,750 / 5,000	0.5	0.9	2.6	14.1
200	7,500 / 10,000	0.9	1.9	5.3	28.2
500	18,750 / 25,000	2.4	4.7	13.4	70.3
1,000	37,500 / 50,000	4.7	9.4	26.7	140.6
1,500	56,250 / 100,000	7.1	14.1	40.0	210.9

[1] Growing season = 120 or 200 days, CF = 2/1, ave feed = 50% of peak
[2] 35% protein, 75% N-release, water column = 0.5 meter
[3] Algal C/N = 5.6/1, C/O2 = 1/1 molar

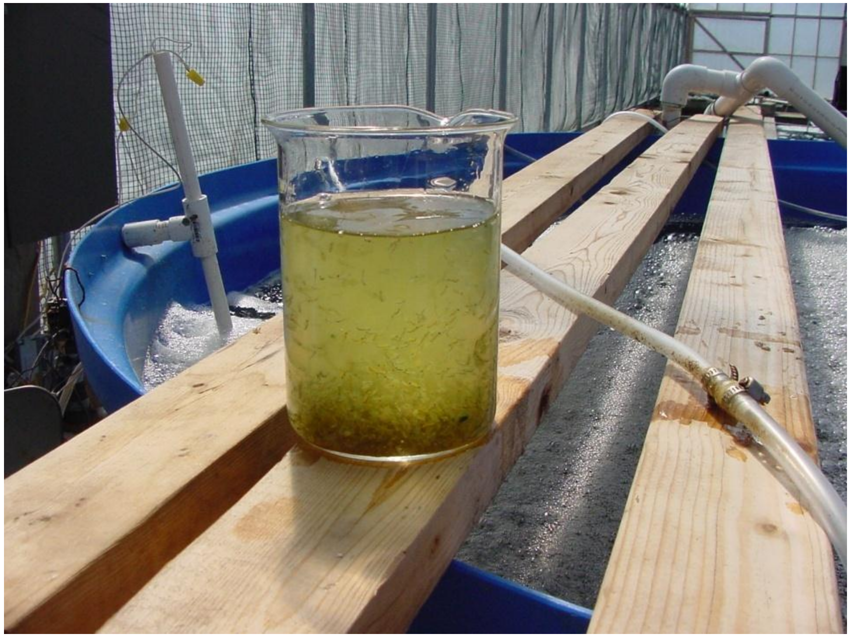
Artemia Brood Reactor, Naupli Production and Starter-Culture

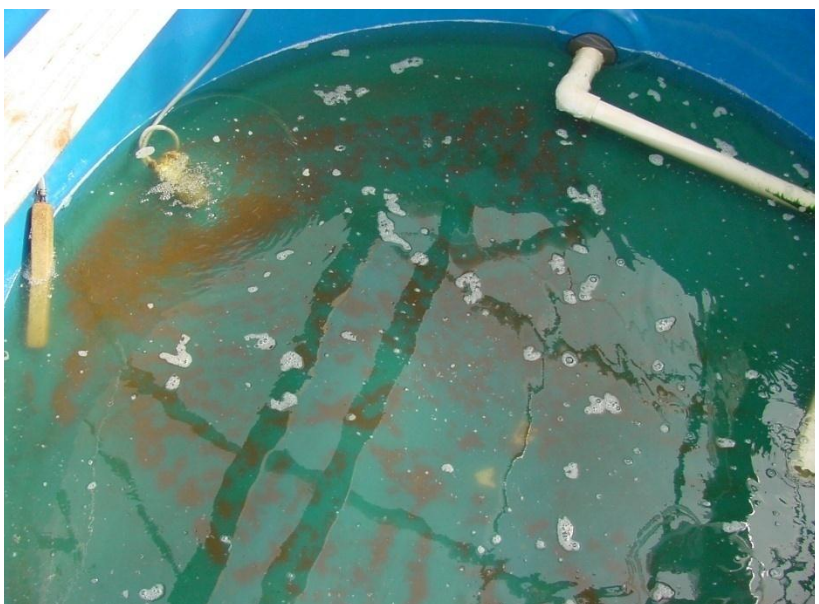


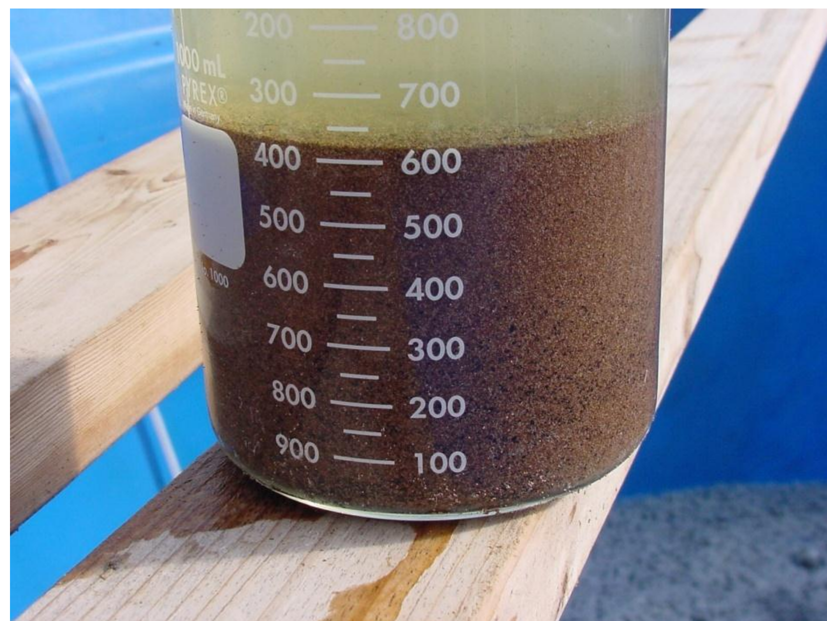
Artemia Growout; Algal Harvest and Conversion

- Air-pulsed screen *Artemia* containment
- Air-lift water and solids removal
- Animal densities; 2-4 per ml
- Hydraulic detention; 25-50 min
- Growth cycle; 15- 20 days

Artemia Cyst Production







Artemia solids removal, concentration and quantification

- Algal solids removal 90- 99%
- Solids concentration ~ 10-20 X

Artemia harvest, density and growth determinations

- 400-800 micron net-harvest
- biomass expansion; 200X/14 days
- 10% solids content; dry ~ 50% protein, 20% lipid

Aquaculture/Bioenergy Co-Production; Cash-Flow Potential

- High-rate algal production maintaining water quality in zero-discharge aquaculture yielding 20,000-25,000 lb/acre-yr fish or shrimp
- Algal biomass of 10-20 tons/acre-yr yielding 5-10 tons/yr fish-meal replacement as *Artemia* biomass
- 4 kw/acre of stationary power (as biogas) with 250-500 gallons of liquid fuel/acre-yr (25 -50% of energy required to operate systems)
- 75-90% of the cash-flow provided by fish or shrimp production, 10-15% from animal feeds, and 5-10% from bioenergy co-production